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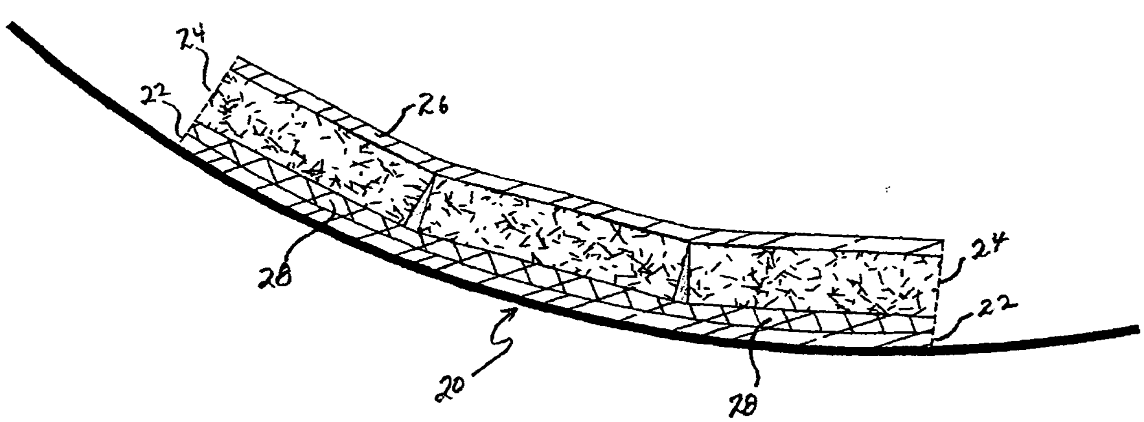
(54) Title: THREE-DIMENSIONAL KNIT SPACER FABRIC SANDWICH COMPOSITE



(57) Abstract: The present invention relates generally to the use of a three-dimensional knit spacer fabric component material in the fabrication of a sandwich core interface composite. More specifically it relates to the use of such a spacer fabric as a skin-to-core laminate interface to enhance laminate bonding, and particularly to enhance the interface planarity of monolithic cores grid cut to approximate curvatures in a mold tool and avoid discontinuities in the composite structure.

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THREE-DIMENSIONAL KNIT SPACER FABRIC SANDWICH COMPOSITE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to the novel use and application of a core material providing improved infusion of a resin and achieving increased stiffness and other properties of a sandwich composite. More specifically it relates to the use of three-dimensional knit spacer fabric as a laminate interface to enhance laminate bonding, and particularly to correct the interfacial planarity of monolithic grid core elements cut and placed to attempts to conform to curvature in the desired structure.

This application is a continuation-in-part of U.S. utility application Serial No. 10/172,053, filed June 17, 2002, and of its underlying Provisional application Serial No. 60/307,109, filed July 23, 2001, the entire disclosures of both of which are incorporated herein by reference. The present application is filed on U.S. Provisional application Serial No. 60/322602, filed Septembr 17, 2001, the entire disclosure of which is alsoincorporated herein by reference.

Description of the State of the Art

Fiber reinforced plastic (FRP) composite structures are generally well known and take many shapes and forms in end applications ranging from marine craft to bathtubs to aircraft, etc., and ranging from simple to complex configurations. Typically the construction of these forms includes providing a reinforcing fibrous structure, woven or non-woven, that is laid up into an open mold of the desired shape, generally referred to as

a preform. Commonly also a core structure is interposed between the internal and external laminae of the composite. This dry fiber reinforcement must then be thoroughly wet out with a curable, generally thermosetting, resin, and generally using manual application techniques. After wetting out, the preform, the resin is then allowed to cure to form the composite of the desired shape. The resulting composite structure is ultimately removed from the mold and after suitable after-treatments may then be used.

Despite the many advantages that such FRP composites exhibit over alternative materials, the property of laminate stiffness (resistance to bending) has not been one of its strong points. Although the following is a generalization with exceptions, such as the use of expensive high modulus fibers, i.e. carbon fiber, and/or advanced, i.e. autoclave, non-economical production processing techniques, FRP laminates are commonly inferior to alternative low-density materials such as wood when the ability of a panel of a given weight to resist bending moments is considered.

The stiffness of a panel, especially an FRP composite panel, is dependent not only on the material's flexural modulus, the measure of the stiffness of the material, but is also generally a function of the cube of the thickness of the panel. Accordingly, while the thickness of such a panel could be increased by some relatively small amount to realize a substantial increase the stiffness of the composite, this also has penalties in weight and expense.

That is, one approach for stiffening an FRP panel would obviously be to make it thicker, but this can result in the disadvantage that an unnecessarily very heavy laminate would result with perhaps unnecessary strength characteristics and also one that is unnecessarily expensive and that may present practical construction problems for the final desired structure.

Fundamentally, the problem of inadequate strength, modulus, can also frequently arise from inadequate uniformity in the FRP composite fabrication. For instance, the resin component may be inadequately distributed throughout the fiber matrix, may have voids therein leading to strength-deteriorating surface discontinuities or may have irregularly cured (e.g., reached a premature gel point) before full distribution of the resin within the fiber matrix had been achieved.

A preferred technique to increase the stiffness of an FRP panel is the use of a sandwich construction. Sandwich construction in a laminate offers the comparable advantages of an I-beam configuration, but instead of the web and flanges of a typical I-beam, a sandwich construction makes use of a light-weight core material faced on one or both sides by skins of FRP. The role of such skins in the composite structure is to withstand the bending moments on the panel or beam by resisting the compressive and tensile loading set up in the opposite skins when the panel is subjected to bending load forces.

For the skins to be able to resist the bending moments they must be rigidly held spaced from the neutral axis of the sandwich (the centerline) and prevented from moving relative to each other. It is the task of the selected core material, and of the bond line strength between the core and the skins, to provide and meet these requirements. For a given industrial application, irrespective of the selected skin and core materials, the integrity of a sandwich construction is especially dependent upon the interfacial bond strength between the skins and the core elements.

The physical or mechanical utilization of the core in a laminate is also very much dependent upon the fabrication techniques employed for a given structure. Those skilled in the art have recognized that, in general, to achieve total and intimate contact between the core elements and the outer skin (when using a female mold, or conversely the inner skin when using a male tool) a vacuum bag technique is usefully employed. In vacuum bag techniques, the skin is laid up and wet out, the core elements applied thereto, with or without a bonding adhesive, and a vacuum bag applied to the assembly. As air is removed, the external ambient air pressure tends to press the core elements uniformly onto the skin surface, however contact between the lamina and the core element is limited by dimensional shape of the core elements. The vacuum bag is commonly left in place until the outside skin (e.g. in a female mold) cures with the core adhered to it. The preparation of the (ultimately) inside fiberglass lamina frequently presents little problem in achieving adequate uniform laminating results because the laminator can visually observe the core surface as the now relatively transparent wet-out fiberglass laminate is prepared. However, serious problems are presented by the FRP skin adjacent to the mold tool where the core elements obscure or prevent visual observation.

Vacuum infusion techniques may be employed to simultaneously fabricate the skins while ambient pressure is applied to the core elements. Where the material for the core elements is relatively rigid and the molded part is designed so as to provide convex or concave surfaces, the core material may be scored into smaller sections, and in some cases a scrim may be applied to one side to hold the small sections together in a planer x,y fashion.

However, the problem frequently encountered is that lateral dimensions of one or more of the scored, commonly rectilinear, core sections may be greater than the radius of the desired mold curvature for the intended structure. This can and does result in a void at the interface of the fiber lay-up and the core elements. In such cases, the ultimate desired intimate contact between the skin and the core can commonly only be achieved through the use of an excess of adhesive or other filler to occupy the resulting dimensional gap.

Such techniques are not practical for vacuum infusion methodology, and in general the skin to core void must be filled with resin. In either case the skin to core gap is filled with a media having remarkably different mechanical and strength characteristics from either the skin or the core, resulting in a region of divergent stress characteristics. Additionally, in applying vacuum infusion, severe voids at the above-described interface may be result from incomplete resin wet out. The resulting interface is then compromised for its optimum desired properties. As a result, discontinuities will be present with an adverse affect on strength of the desired object.

SUMMARY OF THE INVENTION

In view of the foregoing disadvantages inherent in the known types of FRP core and vacuum infusion application techniques now utilized in the prior art, the present invention provides a novel technique for skin to core bonding through the use of three-dimensional knit spacer fabrics as a bond interface in the lay up to achieve greatly enhanced bonding properties.

In particular, the present invention's novel use of a three-dimensional knit spacer

fabric as a skin to core laminae interface, or as an intermediate lamina, enhances the interfacial planarity of monolithic core elements grid cut and departs from the conventional concepts and designs of the prior art. In so doing it provides a technique, material and product developed for the purpose of increasing the FRP skin to core bond line integrity.

The general purpose and result of the present invention, subsequently described in greater detail, is to provide a new skin to core element bond interface having enhanced advantages over the composite sandwich constructions heretofore utilized. To attain this, the present invention generally comprises of the use of a three-dimensional knit spacer fabric having resilient Z-direction fibers used as a lamina within the laminae between the skin and the core. This technique not only provides for an improved skin to core bonding but is also a constituent of the laminate.

Thus, an object of the present invention is to provide a three-dimensional knit spacer fabric with as a bond media between the skin and core in a sandwich composite that will overcome the shortcomings of the prior art devices.

A further object of the present invention is to provide a three-dimensional knit spacer fabric as a bond media between the skin and core in a sandwich composite for use in all processes for composite manufacturing.

Other objects and advantages of the present invention will be apparent to those skilled in the art, and it is intended that these objects and advantages be within the scope of the present invention.

The accomplishment of the above and related objects, this invention may be embodied in the form illustrated in the accompanying drawings, attention being called to the fact, however, that the drawings are illustrative only, and that changes may be made in the specific construction illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 schematically illustrates in cross-section an FRP laminate construction according to the prior art.

Figure 2 schematically illustrates in cross-section an FRP laminate construction according to this invention.

Figure 3 schematically illustrates a three-dimensional spacer fabric used in this invention in its uncompressed state.

Figure 4 schematically illustrates a three-dimensional spacer fabric used in this invention in its compressed state.

Figure 5 is an enlarged schematic illustration of the three-dimensional spacer fabric used in this invention in its uncompressed state.

Figure 6 is an enlarged schematic illustration of the three-dimensional spacer fabric used in this invention in its compressed state.

Figure 7 is a schematic illustration in plan view of another embodiment of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS AND THE INVENTION

As shown in **Figure 1**, a woven or non-woven fiber reinforcement preform layer **(12)** (ultimately, here, the outer skin) is applied to a mold of the desired shape **(10)**. In this example, elements of the core material **(14)** are placed between inner **(12)** and outer **(16)** layers of fiber reinforcement or lamina to make up the laminae structure. In this example the curvature of the mold shape **(10)** is such that a void **(18)** is formed between the outer skin **(12)** and the core elements **(14)**. It is then desired to fill the space **(18)** the resin of choice for bonding the several components of the composite.

However, it is the experience in the prior art the voids **(18)** between the core elements and between such elements **(14)** and lamina **(12)** are frequently difficult to fill completely during fabrication and air spaces or voids occur therein with resulting detrimental effects on the bonding of the composite.

As shown in **Figure 2**, a similar mold tool **(20)** is illustrated, and shown therein an outer skin lamina **(22)**, core elements **(24)**, and an inner skin lamina **(26)**. In this figure the present invention is utilized with the application of the additional lamina **(28)** of the spacer fabric as shown.

Figure 3 is a further schematic illustration of the spacer fabric construction **(30)**. It will be seen that it is composed of two spaced apart woven and/or stitched outer layers **(32)** and **(34)**. Extending between and so made as to connect those two layers are transverse fibers **(36)**. These transverse fibers are so made as to be relative resilient.

Figure 4 is a schematic illustration of the spacer fabric of **Figure 3** but now shown in a compressed state **(40)**, by the application of external pressure. The external layers **(42)** and **(44)** retain fairly well their uncompressed orientation and configuration, but the transverse fibers **(46)** are now angularly displaced with a resultant decrease in thickness of the lamina. The application of pressure and displacement of the transverse fibers **(46)** nonetheless leaves the resilient fibers with a tendency to spring back and resist the deformation. Since the overall spacer fabric is of course flexible, it has the property of

conforming to the irregularities of the shapes of the core elements and of the mold surface itself so that voids therebetween are diminished.

As will be explained below, and as is also described in applicants' parent applications, this spacer fabric, commonly referred to by applicants' by their trademark name "Polybeam™", has the great advantage during fabrication of composite structures of facilitating the flow and dispersion of the liquid resin throughout the fiber/fabric preforms, and thereby as well enabling a filling of voids even as between the core elements prior to a gel point for the resin.

As thus shown in **Figure 2**, and the relate illustrations, by using the three-dimensional spacer fabric **(28)** of this invention placed between the outer skin **(22)** and the core elements **(24)**, the void is replaced by structural FRP reinforcement.

The three-dimensional knit spacer fabric **(50)** in **Figure 5**, for instance, is itself composed of a first woven fabric layer **(52)**, a second fabric layer **(54)**, and the intermediate resilient spacer yarns **(56)**, which may be a monofilament polyester, fiberglass, etc., interconnecting the two layers **(52)** and **(54)**. The fibers of the woven layers **(52)** and **(54)** generally extend in the X and Y directions, as the Figure indicates. The resilient yarns **(56)** extending generally in the Z direction (albeit angled) hold the two fabric layers apart with a free form, pressure-free thickness that may conveniently range from approximately .0625" to 1". A wide range of fabric and yarn fiber types may be used in the spacer yarn, such as polyester, fiberglass, Kevlar, carbon, and combinations. In addition, traditional materials such as fiberglass mat and roving may be stitched or bonded to either or both sides of the three-dimensional knit spacer fabric, and it may also be stitched around other materials. As shown in Figure 5 there is a substantial free, open space between layers **(52)** and **(54)**.

As shown in **Figure 6**, the three-dimensional knit spacer fabric **(60)** is resiliently compressed in the illustrated Z direction when a vacuum (i.e. under ambient pressure) is applied to press the core elements against the skin, as in **Figure 2**. While this spacer fabric is thereby somewhat planarized, it can nonetheless conform to the core-skin interface so that throughout the interface a more uniform reinforced structure is achieved.

The planarized interface may then be infused with adhesive or resin, etc., dependent upon the fabrication technique used, but is preferably filled with resin during the ongoing procedure. Even though compressed as shown in this figure, there remains a significant free open space between the outer layers in that the fiber density continues to be significantly less than that of the outer surfaces. While difficult to measure, calculations presently indicate that while an uncompressed spacer fabric might have about 88-90% free volume, the compressed spacer fabric would still retain about 65 - 75% free volume or open space for resin infusion.

Figure 7 illustrates in plan view an embodiment of the invention and it will be understood that the "Tool" as shown in plan view can signify a mold face having a complex arcuate form. In this instance the "Vacuum" legend signifies that a vacuum is pulled at the upper end of the figure and Resin Input is shown at the bottom. Of course, the precise point of resin input could be elsewhere but is generally most useful at a location relatively remote from the location of the lead to the vacuum pump. In Figure 7 a portion of a spiral cut tube is shown which conveniently serves as a manifold resin entry device. Laminae A and Laminae B as shown in this figure, in each instance including the three-dimensional spacer fabric, are explained in greater detail hereinafter.

One dramatic feature of the use of the three-dimensional spacer fabric according to this invention is that even though compressed under the vacuum applied, there remains a very substantial open space for the infusion of the uncured resin throughout the components of the composite structure. This can be especially visually observed in uncored sample composite as a flow front of the liquid resin as it is introduced through one or more manifold structures in the assembly. As stated in applicants' parent applications, an increase in the speed of movement of this flow front of as much as 200% to 400% may be observed. This important feature has many advantages in the present invention. For instance it permits the use of a wider variation of viscosities for the resin to be utilized. In addition there is always somewhat of a "race" in this technology to achieve a thorough resin infusion or wet-out of the fiber preform prior to the resin reaching its gel point, which would lead to reject of the piece being made. By realizing the higher speed for the flow front of the resin composition, thorough infusion and wet-

out can be more readily achieved under a wider variety of ambient conditions and resin/catalyst combinations.

The practice of the invention will now be illustrated by several examples, it being understood that the invention is in no way limited to the specific conditions illustrated therein.

EXAMPLES OF THE INVENTION

It is quite common to utilized balsa wood core elements within an FRP composite, arranged so that the end grain is normal to the planar surface of the resulting structure. Here, four test panels were fabricated with end-grain balsa core elements, as indicated. The following description sets forth the laminate schedule for each panel. Each panel was fabricated with a Hetron 922 vinyl ester resin and infused and cured under a vacuum of 25 in of Hg.

Panel 1:	18 oz. 3Tex Glass 18 oz. 3Tex Glass 18 oz. 3Tex Glass ¾" CK-89 LamPrep Balsa Polybeam™ 730[1] 18 oz. 3Tex Glass 18 oz. 3Tex Glass	**Panel 2**:	18 oz. 3Tex Glass 18 oz. 3Tex Glass 18 oz. 3Tex Glass ¾" CK-89 LamPrep Balsa Polybeam™ 703[1] 18 oz. 3Tex Glass 18 oz. 3Tex Glass
Panel 3:	18 oz. 3Tex Glass 18 oz. 3Tex Glass Polybeam™ 703[1] ¾" CK-89 LamPrep Balsa Polybeam™ 703[1] 18 oz. 3Tex Glass 18 oz. 3Tex Glass 18 oz. 3Tex Glass	**Panel 4**:	18 oz. Glass 18 oz. Glass 18 oz. Glass ¾" CK-89 LamPrep Balsa 18 oz. Glass 18 oz. Glass 18 oz. Glass

[1] Note: Polybeam™ is the trademark for the spacer fabric used in these panels.

Polybeam™ 730 fabric is a three bar Raschel knitted spacer fabric from a double bed machine having the following characteristics:

The wales/meter are 590, The courses/meter are 530
(wale = vertical line of stiches; course = horizontal line of stitches). The yarn is understood to be 100% monofilement polyester of about 0.2mm diameter.
The lapping for this structure is as follows:-
bar 1 02,22,20,00,02,66,810,1010,108,88,810,66,
bar 2 (20,46,810,64,) x 3
bar 3 66,810,1010,108,88,810,66,20,00,02,22,02,
0 -2 is a one needle shog (displacement). The trick plate gap is 10mm.

Polybeam™ 703 is a similar Raschel knitted spacer fabric having similar characteristics:

The inner and outer "skins" are of an orthogonally woven fiberglass material, supplied from 3Tex.

After curing, two tests were performed on the panels.
Test #1, ASTM C-393 "Flexure Test", is an evaluation of the stiffness and strength of sandwich panel specimens subjected to bending loads.
Test #2, ASTM C-297 "Flat-wise Tension Test", is an evaluation of the tensile strength and modulus of structural cores in a direction perpendicular to the sandwich facings. Edgewise loading of a sandwich panel can induce buckling on the faces of the sandwich panel. This outward buckling is representative of these flat-wise stresses.
Results:

Test	ASTM C-297 Tensile Strength and Modulus		ASTM C-393 Flexural Stiffness and Modulus		
	Strength(psi)	Modulus(psi)	Stiffness(in*lbf) Mold Side/Backside	Modulus(psi) Mold Side/ Backside	Deflect @ 100lbs(in) Mold Side/ Backside
Panel 1	1164	30356.3	53642.4 / 53888.4	20700.2 / 21049.1	0.045 / 0.045
Panel 2	1083	27506.1	45069.3 / 43350.0	19350.9 / 18681.1	0.054 / 0.056
Panel 3	877.2	25944.7	51947.5 / 51592.7	21128.7 / 20435.9	0.047 / 0.047
Panel 4	1205.4	28016.2	50772.9 / 49408.1	22361.4 / 21922.7	0.046 / 0.049

These test results demonstrate no deleterious effect on the composite strength characteristics from the use of the spacer Polybeam™ fabric, even though its structure having opposed spaced apart fabric layers clearly includes in both uncompressed and compressed form an interior region of greatly reduced fiber density.

A significant observed result of this testing was that tensile failure always occurred between the core (balsa element) and the skin. Failures never occurred on the side of the balsa core elements that were bonded in contact with the spacer fabric. In fact for Panel 3 which has Polybeam™ 703 on both sides of the core. The outer 3Tex glass fiber skins failed and the core element failed, but the Polybeam™ to core interface always remained intact.

Test panel fabrication:

In order to evaluate the mechanical properties of a Polybeam™ containing laminate additional flat test panels were fabricated. Dimensional considerations were dictated by the requirements of the selected ASTM tests. The laminates were thus selected on this basis to yield composites of the appropriate thickness. Selected laminae schedules are tabled below (see also Figure 7 for an illustration.

ASTM D3039 Tensile Test of Fiber-Resin Composites
ASTM D790 Three-Point Flexural Test

Lamina	Material	Warp Orientation	Ply Orientation[1]
1	E-LTM 2415-7	0°	-
2	Polybeam™ 730	0°	NA
3	E-LTM 2415-7	0°	-

Table 1. Laminae A

ASTM D790 Three-Point Flexural Test

Lamina	Material	Warp Orientation	Ply Orientation
1	E-LTM 2415-7	0°	-
2	Polybeam™ 730	0°	NA
3	E-LTM 2415-7	0°	-
4	E-LTM 2415-7	0°	-
5	Polybeam™ 730	0°	NA
6	E-LTM 2415-7	0°	-

Table 2. Laminae B

[1]2415 is 24 oz./yd^2 biaxial stitched roving with 1.5 oz./ft.^{2} CSM stitch to one side. Here (-) refers to the mat up, with the roving against the Polybeam™.

Laminae A is designed to provide a laminate ~ .157" in thickness (4 mm) and Laminae B is designed to provide a laminate ~ .354" in thickness (9 mm) per the ASTM standard requirements.

The reinforcing lamina are comprised of stitch bound fiberglass, supplied from Johnson Industries, and having the following characteristics:

Johnston Identification:	E-LTM 2415-7
Fiber Type:	Fiberglass (E)
Architecture:	0°/90° Biaxial "LT" series
Dry Thickness:	0.066 in. / 1.6764 mm
Total Weight:	39.08 oz/yd^2 / 1291.41 g/m^2

Fiber Architecture Data

0°:	12.03 oz/yd^2 / 304.64 g/m^2
90°:	11.95 oz/yd^2 / 405.06 g/m^2
mat/veil:	13.5 oz/yd^2 / 1.5 oz/ft^2

Fabrication Process:

To accommodate sample requirements as stated above a single 24" x 24" panel was fabricated. The tool was comprised of a wax release treated 48" x 48" flat Formica plate. Laminae A (Table 1) was accomplished but cutting the lamina to the 24" x 24" dimension and placing them in the specified sequence onto the tool surface. Laminae B (in Table 2) was accomplished by repeating the ply stacking sequence of Laminae A in a 6" x 24" lamina in the correct orientation on top of Group A in alignment with one edge. A single vacuum port was fitted adjacent to Laminae B and spiral cut tubing wrap for resin input was fitted on the opposite edge of Laminae A, again as shown in Figure 7. A flexible vacuum bag was then fitted and sealed about the laminate, the resin input tube sealed with a clamp, and vacuum drawn.

Vacuum was read by a gauge affixed to a standard resin trap. When vacuum reached 26" Hg, the clamp was removed from the resin inlet tube, and the tube was subsequently placed in the vinylester resin (~230 cps.). A uniform flow front across the part was noted. The resin clamp was reaffixed to the inlet tube when the resin front reached the vacuum port. Full vacuum (26" Hg.) was maintained during this process. At

this point, excess resin within the laminate is pulled out by vacuum until the point in time at which the resin gels and can no longer flow. Full vacuum is maintained until such time. After the resin completed its exotherm and has cooled to room temperature, the panel was removed for post cure and testing. During this test the following conditions were observed:

Room temperature: ~68°F
Resin temperature: ~68°F
Tooling temperature: ~68°F
Viscosity was specified as 230 cps. at 77° F.

Fiber volume: Typical fiber/resin ratio ranges for vacuum infusion within the laminate (sans the infusion media) are from 40:60 to 75:35. These ranges are based on weight and are therefore very dependent upon the constituents used, both in terms of the resin and the fiber. It will accordingly be understood that this invention is in no way limited to these particular ratios.

It will be apparent to those skilled in the art that the advantages and utility provided by this invention can be realized by the use of a wide variety of fiber sizes and of fiber composition. Glass fibers are commonly widely used but other fibers such as carbon fibers or Kevlar polyaromatic fibers can also be employed. Similarly, a wide range of thermosetting resins (epoxies, vinyl and other cross-linkable materials) are also adapted for this utility. What has essentially been discovered, in contrast to prior art utilizations of three-dimensional spacer fabrics is that they have this special capability of permitting a more rapid, enhanced introduction and flow of resin into and through the composite layup. Surprisingly, this characteristic remains present even under a vacuum applied compression of the spacer fabric. Moreover, because the spacer or Z-direction fibers (see illustrations in Figures 6 and 7) retain a resiliency, there is an embedded tendency for the structure to spring back thus filling what otherwise might be undesirable voids and cavities or comparable discontinuities in the ultimate cured composite. This spring back is in fact aided by the lubrication introduced by the resin infusion, lowering the interactive fiber-to-fiber friction otherwise present in the dry material. The resultant composite therefore exhibits a higher degree of integrity and uniformity, not only in its structure but also in its ultimate strength characteristics. Significant economies in

production processing are a further benefit of the use of this invention in that less wastage and off-spec products are realized.

The advantages of this invention are presently believed to be most completely realized with at least one monolithic core element disposed between the outermost preforms laid up on a mold surface and using vacuum bag means to induce a negative pressure and consequent curable resin flow in communication with the three-dimensional spacer fabric. It is a feature of this invention that the resultant relatively high velocity flow of the curable resin also provides thorough lateral wet-out of the adjacent fiber fabric layers even though they themselves do not possess the three-dimensional spacer fabric structure, so that a uniform resin infusion is achieved throughout the composite laminate. Of course, this invention can also be employed with many different mold forms, and it is likewise adapted for use in closed mold technologies as well as open mold technologies as described.

Accordingly, this invention is limited only by the spirit and scope of the appended claims.

We claim:

1. An article of manufacture composed of a fiber-reinforced composite laminate composed of at least one woven or non-woven side fiber-containing face and an opposed woven or non-woven fiber-containing face and disposed therebetween at least one interlaminate three-dimensional spacer fabric structure said latter structure having a first woven fabric layer with fibers generally lying in a first X and Y plane, a second woven fabric layer also with fibers generally lying in a second X and Y plane, and therebetween a plurality of spacer fibers generally extending in a Z direction and interconnecting said first and second fabric layers, and providing a substantial lateral free path for resin infusion through and between said first and second fabric layers, said entire composite laminate being substantially saturated with a curable resin.

2. A method for forming an fiber-reinforced composite laminate comprising the steps of

laying down on a mold surface at least one first preform composed of a woven or non-woven fiber structure, applying thereon a three-dimensional spacer fabric composed of

a first woven fabric layer with fibers generally lying in a first X and Y plane, a second woven fabric layer also with fibers generally lying in a second X and Y plane, and therebetween a plurality of spacer fibers generally extending in a Z direction and interconnecting said first and second fabric layers,

applying thereupon a second preform composed of a woven or non-woven fiber structure,

enclosing the resulting lay-up within a vacuum bag,

providing means for applying a vacuum to the enclosure of said vacuum bag,

providing means for introducing a curable resin composition along at least one side of said vacuum bag and in communication with at least said three-dimensional spacer fabric,

and introducing said resin for flow through and wetting out of said entire fiber structure.

3. The method of claim 2 wherein at least one monolithic core element is also provided in between at least a portion of said first or second fiber lay-up and said three-dimensional spacer fabric

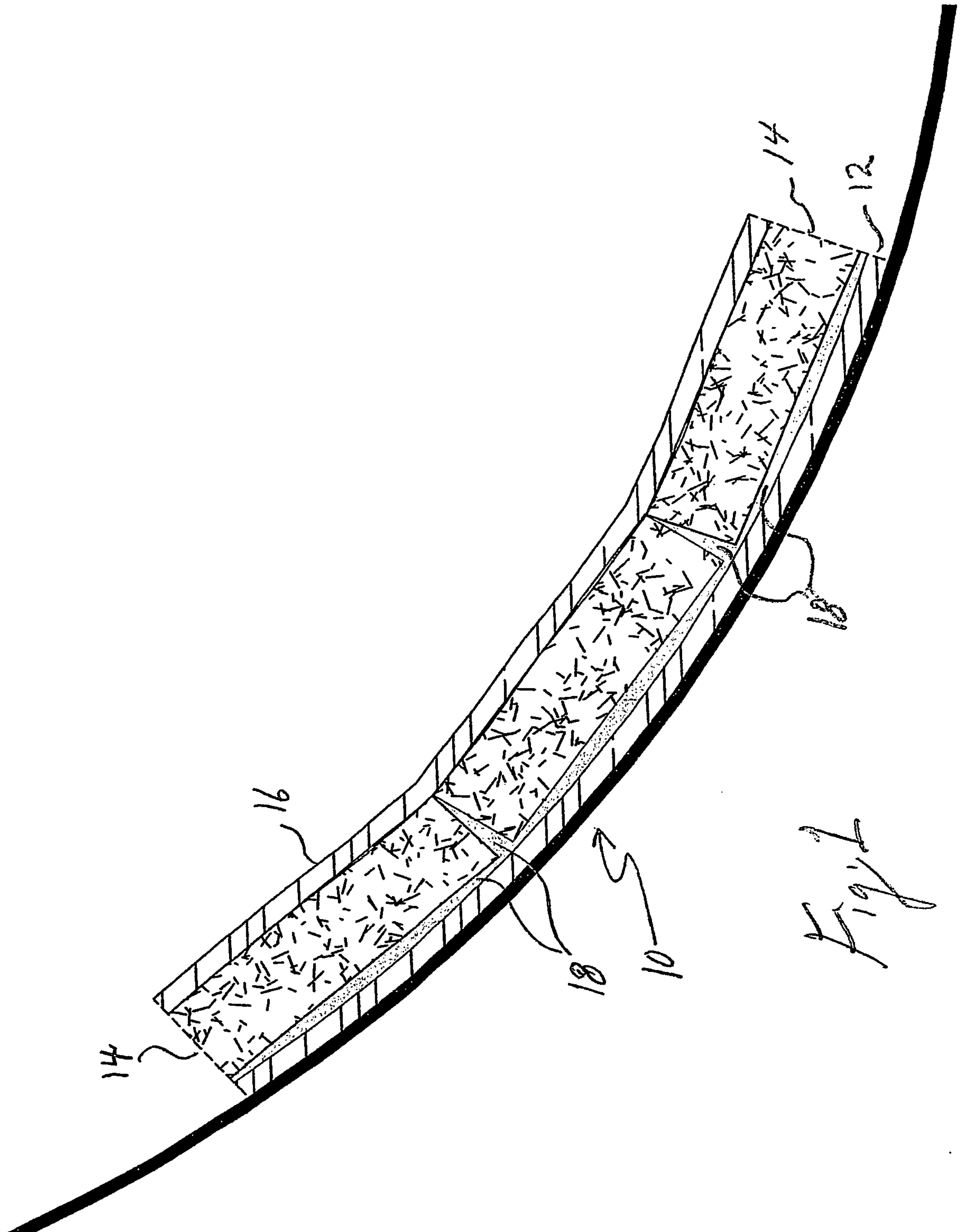
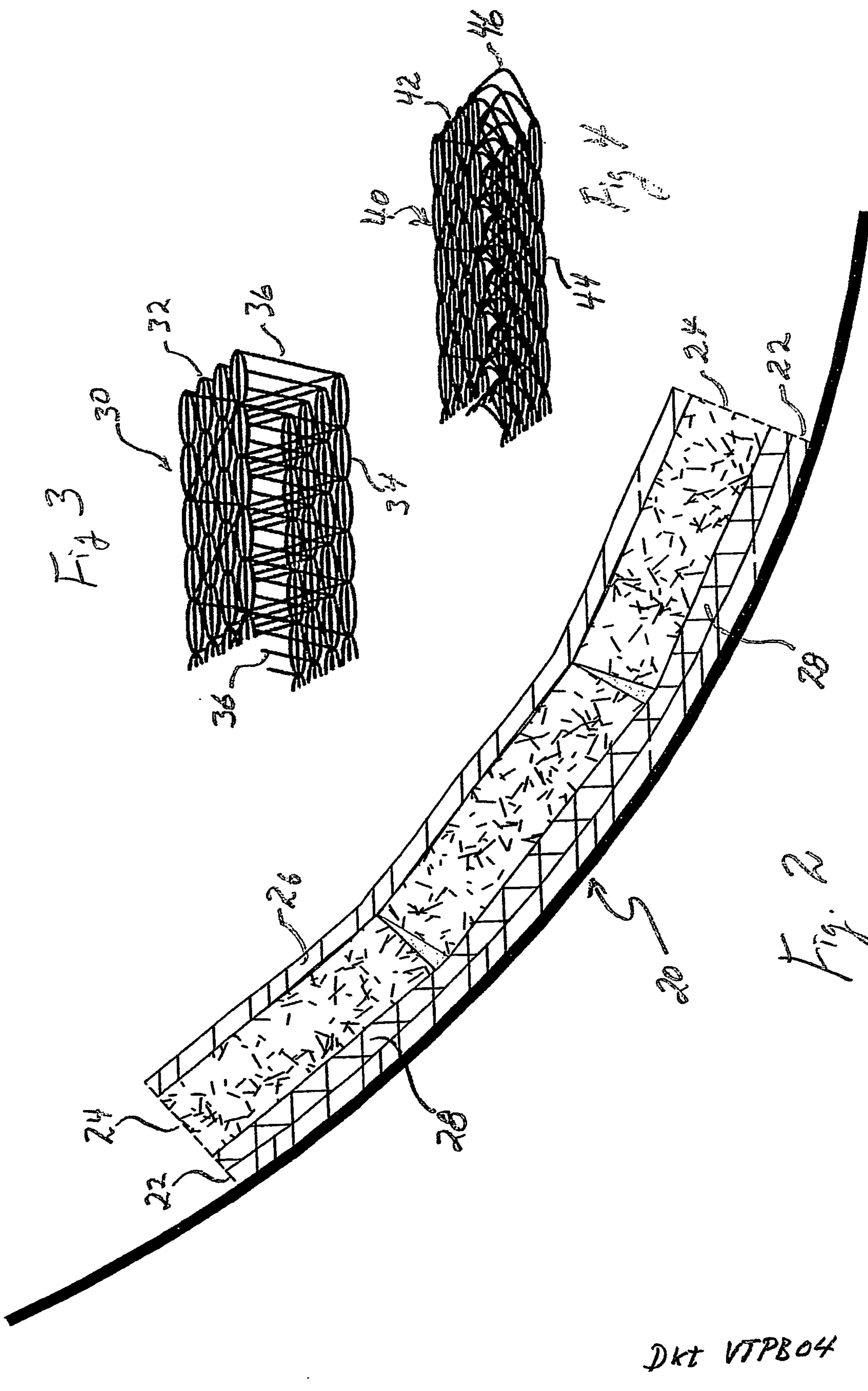


Fig 1

Dkt VTPB04



Dkt VTPB04

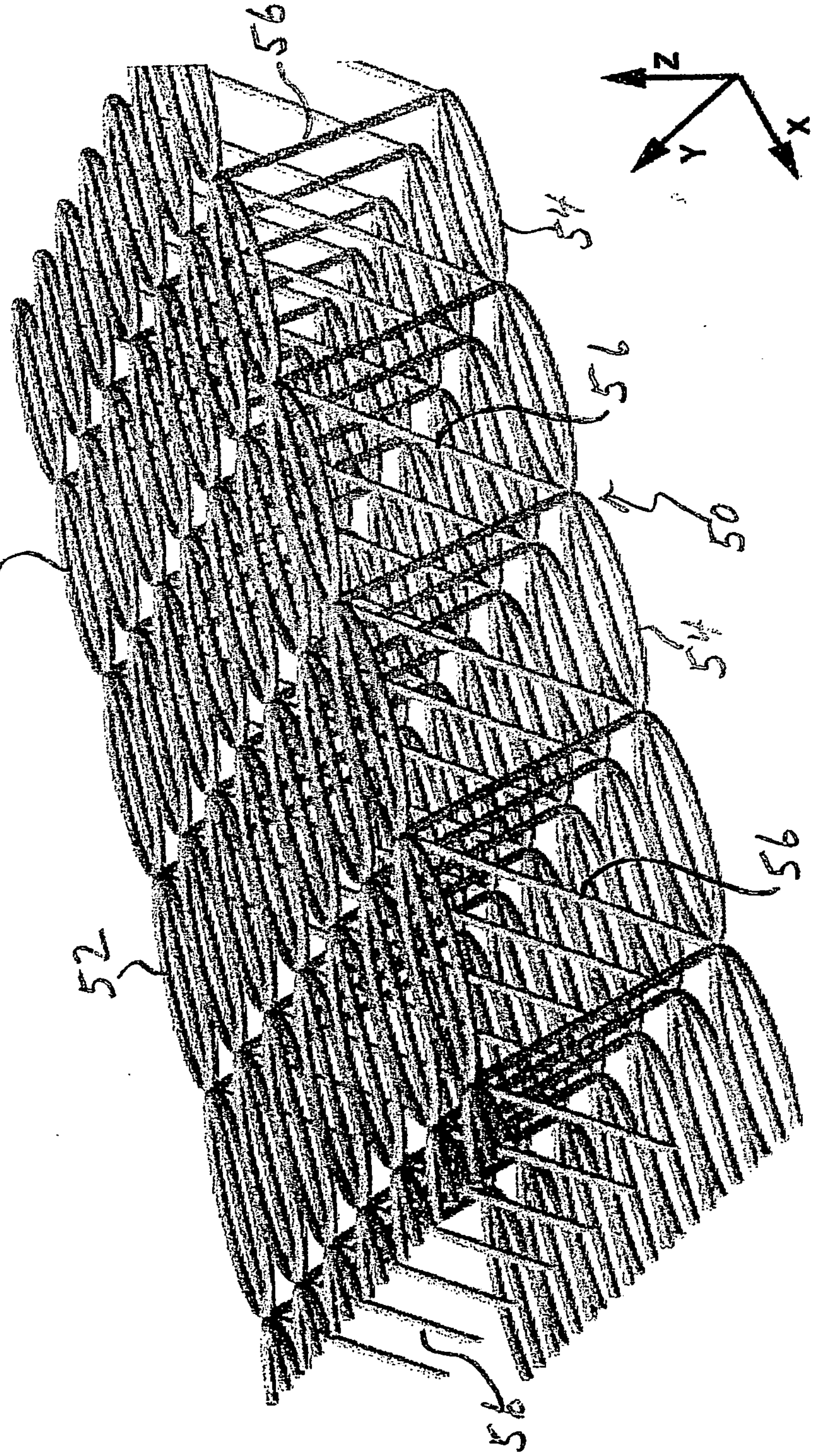


Fig. 5

Dkt VTPB04

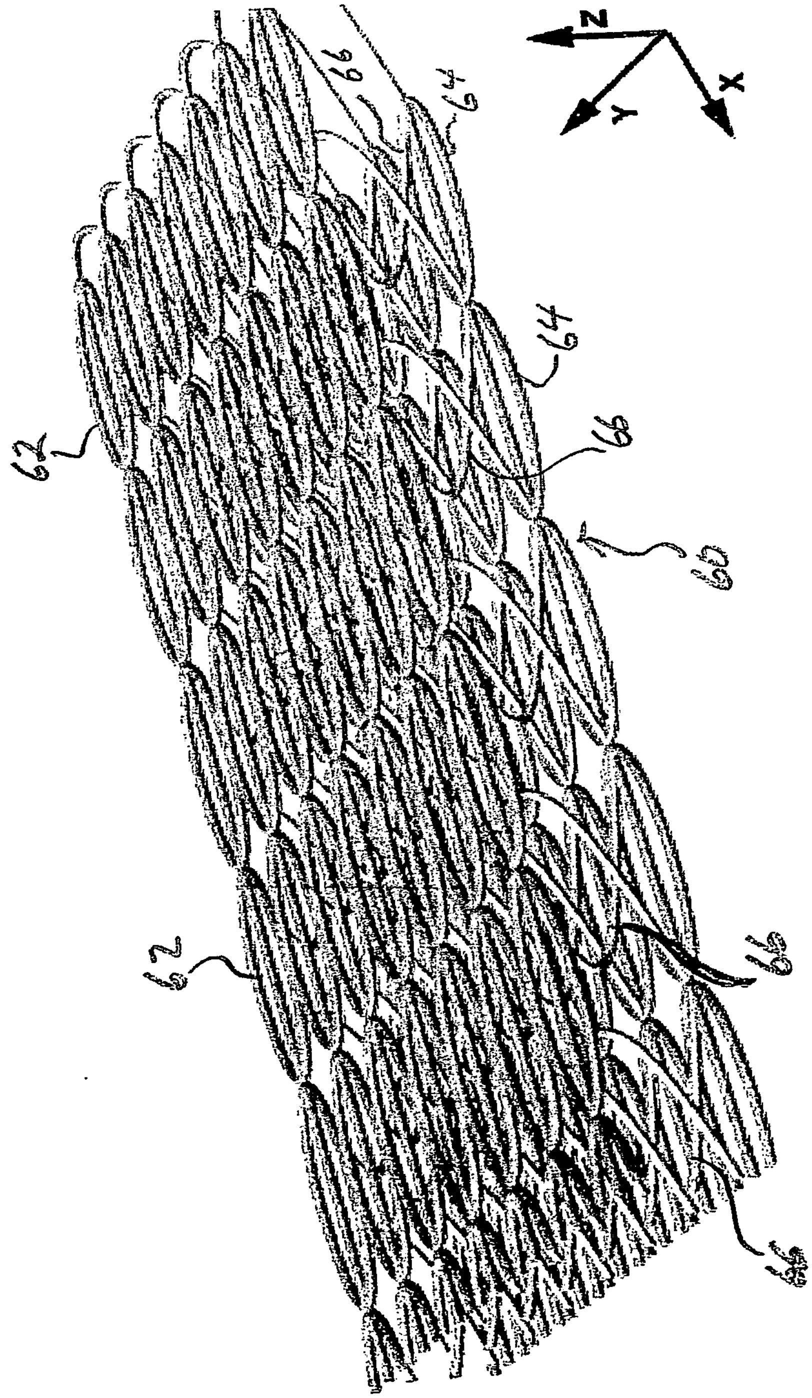


Fig. 6

Dkt VTPB04

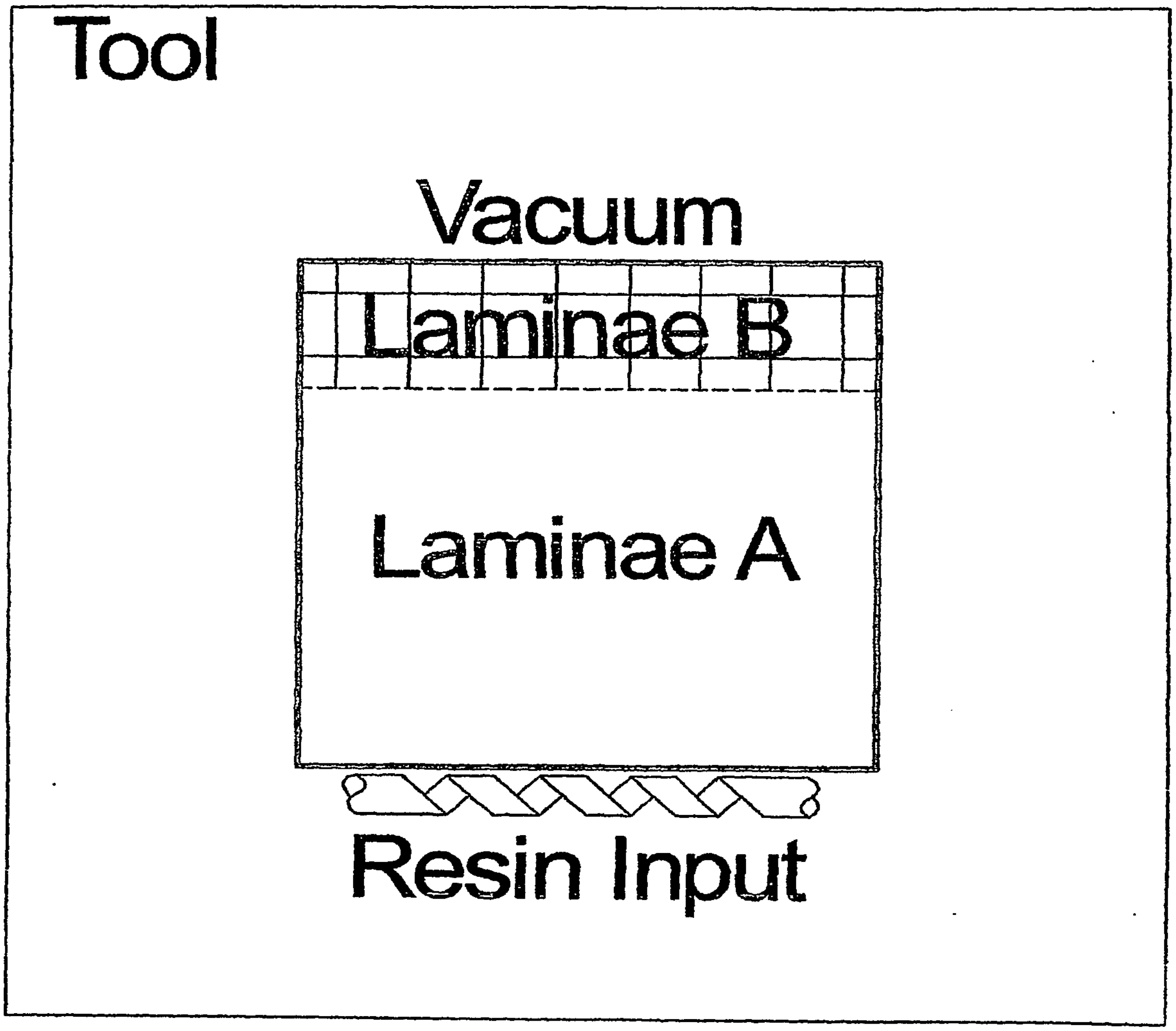


Fig. 7

DKt VTPB04

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/29312

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B32B5/08 B32B27/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 D04B B32B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 580 412 A (FANTINO MARCO) 3 December 1996 (1996-12-03) column 1, line 49 -column 2, line 31 column 2, line 64 -column 3, line 53 figures 1,10-15	1,2
X	US 4 389 447 A (DISSELBECK DIETER ET AL) 21 June 1983 (1983-06-21) column 1, line 62 -column 3, line 42	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 January 2003	27/01/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Stinchcombe, J

INTERNATIONAL SEARCH REPORT

Internat ıpplication No
PCT/US 02/29312

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